Site Factors and Seeding Methods Affecting Germination and Survival of Tree Species Direct-Seeded on Surface-Mined Areas

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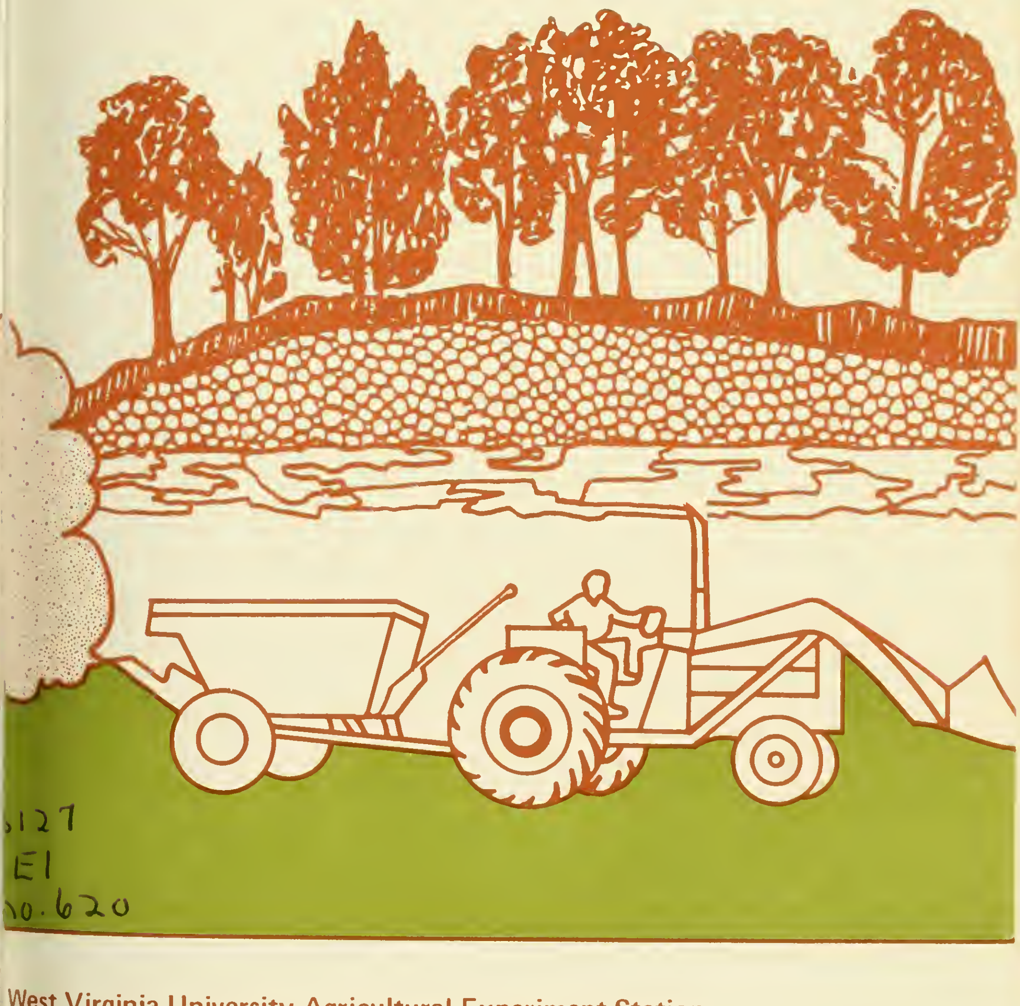

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Site Factors and Seeding Methods Affecting Germination and Survival of Tree Species Direct-Seeded on Surface-Mined Areas

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Introduction

MORE THAN 200,000 acres of land have been directly affected by surface-mining for coal in West Virginia, and approximately 10,000 acres are being added to this figure annually. Initially, spoil banks formed during surface-mining are bare of vegetation. This may cause increased run-off of water, erosion, stream pollution, landslides, and slips. Revegetation is needed to stabilize these areas and return them to a productive condition.

In West Virginia, direct-seeding of black locust was the most commonly used method of attempting to reforest surfaced-mined lands during the 1940s and 1950s. The effectiveness of this practice was evaluated by Brown and Tryon (1960). Their study of a random sample of approximately 20,000 acres of spoil bank area indicated that direct-seeding of black locust had given successful stands of trees on only about 20 per cent of the area on which the practice had been used. Almost 50 per cent of the stands were rated as complete failures, while the remaining 30 per cent were rated as partial failures. Planting of nursery grown seedlings was much more successful. Brown (1962) found that successful stands of trees were established on almost 75 per cent of the spoil bank area planted in the State, while stands were rated as failures on only 6 per cent of the total area planted. A later evaluation of plantings made by Soil Conservation Districts in West Virginia reported similar results (Mellinger *et al.*, 1966).

A number of site factors have been shown to be related to germination, establishment and growth of tree seedlings on surface-mined sites. Spoil acidity has been the chemical factor most closely correlated with establishment and growth and there is usually little or no plant growth on spoils where pH is below 4.0 (Brown, 1962; Brown and Tryon, 1960; Finn, 1958; Limstrom, 1960; Mellinger *et al.*, 1966). Although nutrient deficiencies normally are not limiting on surface-mined areas, nitrogen and phosphorous may be low, and lack of these elements can retard quick establishment and growth of vegetation on some areas (Croxton, 1928; Cummins *et al.*, 1965; Finn, 1953; Limstrom, 1960; Limstrom

and Deitschman, 1951). Excesses of certain elements—notably iron, aluminum and manganese—may be more serious, and toxicity of these elements is usually associated with high acidity (Berg and Vogel, 1968; Cummins *et al.*, 1965 Limstrom, 1960).

Physical properties of spoil material also affect establishment and growth on surface-mined sites. Texture of spoil material is quite variable on different spoil banks and within limited areas on the same site (Bramble, 1952; Limstrom and Merz, 1949; Potter *et al.*, 1951). Initially, spoil materials are usually single grained, with little or no aggregation into larger structural units (Wilson, 1957) As a consequence, regrading can cause severe compaction, particularly on fine textured materials, and establishment and growth of vegetation may be retarded (Brown, 1962 and 1973; Deitschman, 1950; Limstrom, 1952 and 1960).

Topographic factors also may have important effects on vegetation growing on surface-mined sites. Many of these have indirect effects on moisture available for plant growth. Survival and growth generally have been shown to be best at or near the bottom of slopes and on areas with low slope per cent (Brown, 1962 and 1973; Brown and Tryon, 1960; Clark, 1954; Deitschman and Lane, 1952) Aspect also may be important, and better correlation has been found between aspect and establishment and survival than with growth (Clark, 1954; Limstrom 1960; Limstrom and Deitschman, 1951). The effects of aspect have been found to be related to indirect influences on soil moisture (Limstrom, 1952) and to direct effects of high temperatures on mortality and growth of seedlings (Bramble, 1952; Grandt and Lang, 1958; Schramm, 1966).

In the past few years there has been a renewal of interest in the use of direct-seeding as a method for reforestation of areas surface-mined for coal Much of this interest has resulted from four factors: (1) the cost of planting nursery grown seedlings has increased considerably and surface mine operators would like to find an effective, less costly alternative to planting of seedling stock; (2) it is becoming increasingly difficult to hire personnel who are willing to perform field tasks such as planting; (3) many areas, such as long, steep outer slopes of some spoil banks are difficult and even dangerous to plant with nursery grown stock; and (4) the development of new seeding methods and equipment such as hydro-seeders and the use of helicopters may give better results than were obtained in the past from direct-seeding.

The purposes of the study reported here were: (1) to investigate the effects of selected site factors on the germination and survival of tree species direct-seeded on surface-mined areas; and (2) to compare the effects of different seeding methods on germination and survival of different tree species. It was hoped that results obtained would provide a basis for recommendations which would lead to more successful direct-seedings on surface-mined areas.

Procedure

The experimental areas used in this study are located near Reedsville in Preston County, West Virginia, at an elevation of 2,100 feet. The spoil banks on which plots were located were formed from surface mining of the Bakerstown Coal seam. Sampling of spoil material indicated that textures ranged from medium to moderately fine and averaged in the clay-loam textural class. Acidity ranged from very strongly acid (pH 4.6) to medium acid (pH 5.6), with an average pH of 4.9. There was no predictable pattern to the variability in either texture of pH and the range of values was approximately the same on all areas.

Three separate seeding experiments were established in the study.

1958 BROADCAST-SEEDING EXPERIMENTS

In this study, unscarified black locust (*Robinia pseudoacacia* L.) seed was broadcast-seeded to study the germination and survival of seedlings on areas having different aspects, degrees of compaction and vegetative cover. Four areas were used: southwest- and northeast-facing slopes which had been severely compacted during regrading of the spoil surface; and southwest- and northeast-facing slopes which had received little or no regrading. Slopes on all areas ranged from 10 to 15 per cent. A light cover of herbaceous plants composed primarily of broomsedge (*Andropogon virginicus* L.) was present on the graded areas, while there was little or no herb cover on the ungraded sites.

In April, 1958, two plots were laid out on each of the ungraded areas, and four were laid out on each of the graded sites. Vegetation was removed from two randomly selected plots on the graded areas. All plots were 25 feet by 25 feet. To facilitate the exact location of seedlings in later germination and survival counts, markers were placed at one-foot intervals along the edge of each plot.

After all plot layout had been completed, Bouyoucos soil moisture blocks were placed at depths of two inches and twelve inches in the spoil at two randomly located points in each plot. Maximum recording thermometers also were placed at each location, with the upper surface of the mercury bulb exposed at approximately the surface of the spoil.

In early May, 1958, all plots were seeded with 65 grams of black locust seed—a seeding rate equivalent to 10 pounds per acre. Characteristics of the seedlot used are given in Table 1. Each plot received approximately 3,000 viable seed or an average of about five viable seed per square foot.

Beginning one week after seeding and at intervals of approximately ten days thereafter throughout the summer, each one square foot area on all plots was examined and the location of each seedling was mapped on grid paper. In this way, germination, survival and mortality of all seedlings were followed closely throughout the growing season. For purposes of this study, and the spot seedings made in 1959 and 1960, germinated seedlings were defined as those for which a

TABLE 1. Characteristics of seedlots used in direct-seeding trials on surface-mined areas.

Year Seeded	Species	Clean seed / lb.	Soundness[1]	Germination
		No.	per cent	
1958	Black locust, unscarified	26,000	98	85
1959	White pine	25,000	80	68
1959	Pitch pine	59,000	78	62
1959	Black locust, unscarified	26,000	99	87
1959	Black locust, scarified	26,000	98	86
1960	Virginia pine	61,000	56	41
1960	Black locust, unscarified	26,000	99	84
1960	Black locust, scarified	26,000	99	85
1960	Pitch pine	59,000	80	66

[1]Soundness: Per cent of seedlot with filled and apparently sound seed as determined b cutting test.

[2]Germination per cent: Germination of seedlings during 90-day period in the greenhouse

radicle had appeared and become sufficiently established to give an uprigh seedling. Each time germination and survival counts were made, soil moistur readings (in ohms resistance) were taken and maximum temperature readings fo the period were recorded. Four additional germination and survival counts wer made the following spring and early summer (1959) to check winter mortalit and delayed germination of black locust seed.

Following completion of field work, samples of spoil material wer collected and a calibration curve was constructed relating resistance readings (in ohms) to per cent moisture by weight, using the method described b Bouyoucos and Mick (1940). Resistance readings taken in the field were ther converted to per cent moisture by weight to provide a more easily understood picture of differences due to the site factors studied. In addition, the wate retention of spoil material at field capacity (-1/3 bar matric potential) and wilting point (-15 bar matric potential) was determined using porous plate and pressure membrane apparatus.

Since it was impossible to duplicate different aspects and degrees of compaction on the same area, the experimental design used in the study did not conform strictly to statistical standards for randomization and replication. However, statistical analyses did provide for approximate comparisons of the effects of aspect and vegetation on vegetated sites and the effects of aspect and compaction on unvegetated sites.

1959 SPOT-SEEDING EXPERIMENTS

This study was designed to investigate the effects of different methods of seeding on germination and survival of seedlings of different tree species. The experimental area used was adjacent to those used for the 1958 experiments and it was flat. Three species were used: white pine (*Pinus strobus* L.), pitch pine (*Pinus rigida* Mill.) and black locust (unscarified and scarified seed). Three seeding methods were used: surface-seeding; covering seed with one-fourth inch of spoil material; and covering seed with one-fourth inch of spoil material plus mulching of seed spots. Characteristics of the seedlots used are given in Table 1. Ten seed per spot were used, with ten spots per replication and five replications. A randomized complete block experimental design was used, and the means of the ten spots in each species-method of seeding-replication combination were used as items in all analyses of variance.

Spots were seeded in early May and germination and survival counts were made at approximately weekly intervals on all spots throughout the summer. Three additional counts were made the following spring (1960) to check winter mortality of seedlings and delayed germination of seed.

1960 SPOT-SEEDING EXPERIMENTS

This study was similar to that established in 1959 and was located on the same site. Three species were used: Virginia pine (*Pinus virginiana* Mill.), pitch pine and black locust (unscarified and scarified seed). Two seeding methods were employed: surface-seeding and covering seed with one-fourth inch of spoil material. Characteristics of seedlots used are given in Table 1. Installation of plots, measurements and analyses were similar to those used for the 1959 study except that four replications were used in the 1960 study instead of five.

Results

Results obtained in the three series of experiments showed significant differences in germination and survival due to the effects of the site factors and species combinations studied. There were also significant differences in germination and mortality during different time periods for individual species-site factor combinations. To make the presentation of data more meaningful, values have been converted to numbers per acre for the 1958 broadcast-seeding and numbers per thousand seed spots for the 1959 and 1960 spot-seedings.

1958 BROADCAST-SEEDING EXPERIMENTS

Aspect, compaction and herbaceous cover had significant effects on germination, mortality and survival of broadcast-seeded, unscarified black locust seed and seedlings. The total number of seed that germinated was approximately 50 per cent greater on northeast-facing slopes than on southwest-facing ones. Although total mortality was highest on northeast-facing areas (because of the

greater number of seed which germinated), the number of established seedlin alive at the end of the study period in the summer of 1959 was over three tim greater on northeast-facing slopes than on southwest-facing ones (Table 2, Figu 1, Appendix Table 1). Such differences in establishment and growth of tr species on surface-mined areas and on other sites having different aspects al have been noted in other studies (Brown, 1973; Clark, 1954; Finn, 195 Limstrom and Deitschman, 1951; Mickler and Chapman, 1954; Schramr 1966).

The effects of severe regrading and compaction of the spoil surface w compared on sites having no herbaceous cover. Germination on ungraded sit was nearly three times as great as on graded ones, and the number of trees livir in the summer of 1959 was approximately 60 per cent higher on ungraded are (Table 2, Figure 1, Appendix Table 1). Similar detrimental effects of grading spoil material on survival and growth of tree species also have been found other studies (Brown, 1973; Limstrom, 1952 and 1960; Potter *et al.*, 1951).

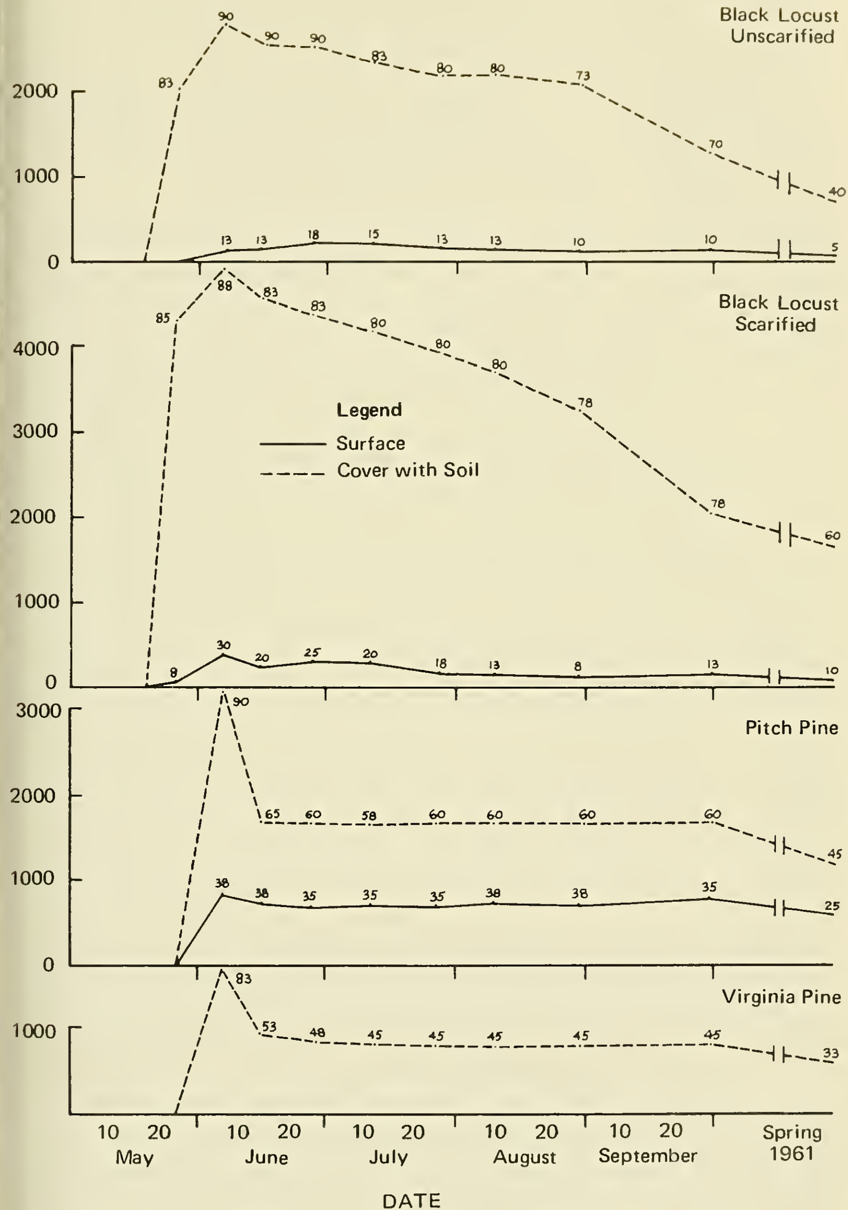
The presence of a light herbaceous cover had drastic effects on germinatic and mortality of black locust seed and seedlings. Germination and the number trees living at the end of the study period were nearly eight times greater c graded sites having no herb cover than on similar areas having a light cover broomsedge (Table 2, Figure 1, Appendix Table 1). Several other studies al have shown that the presence of herbaceous cover can reduce germination ar survival of seedlings on direct-seeded areas (Bonner, 1965; Little *et al.*, 195 Mann and Derr, 1961; Smithers, 1965; Sowers, 1965).

Two fairly distinct patterns of germination and mortality were obvious fro the periodic counts made during the summer of 1958 (Figure 1, Appendix Tab 1). On ungraded areas on northeast- and southwest-facing slopes there was large flush of germination shortly after seeding and the maximum number living seedlings was recorded during the last two weeks in June. Although th

TABLE 2. Total germination and mortality of black locust seed and seedling on surface-mined areas broadcast-seeded in 1958.[1]

Site Condition		Aspect					
Grading	Herb. Cover	Northeast Germ.	Northeast Mort.	Southwest Germ.	Southwest Mort.	Average Germ.	Average Mor
		Number of seedlings per acre					
Graded	None	9,058	8,714	5,110	4,993	7,084	6,8
Graded	Light	1,160	1,102	1,044	1,044	1,052	1,0
Ungraded	None	21,414	20,834	16,874	16,699	19,144	18,7
Average		10,543	10,217	7,676	7,579	9,110	8,8

[1]See Appendix Table 1 for periodic counts of germination and mortality of seedlings.



IGURE 1. Variation in numbers of living seedlings and per cent stocking of plots umbers over plotted points) for broadcast-seeded black locust on surface-mined areas.

amount of germination and mortality fluctuated after this, mortality genera exceeded germination and there was a gradual decrease in the number of livi trees on the study area throughout the summer.

On graded areas (northeast and southwest slopes) a different pattern w noted. Germination began more slowly and there was a gradual increase in t number of living trees, with the maximum being reached in late July and ea August. After this, the number of living trees dropped sharply.

On those areas where there was a light herbaceous cover (graded sites onl germination remained very low throughout the summer and there was appreciable increase in the number of living seedlings. Maximum numbers we reached in late July and early August, with no significant differences due aspect during the different time periods.

Stocking of plots followed the same general trends shown for germinati mortality and numbers of living trees. However, the magnitude of differen generally were not so great (Figure 1, Appendix Table 1). Average per ce stocking was significantly highest on northeast slopes, ungraded areas and are without herbaceous cover. However, maximum stocking was approximately t same on northeast- and southwest-facing slopes and on graded and ungrad areas. Maximums for areas with no herbaceous cover (graded sites only) we much higher than were those for areas having a light herbaceous cover.

Variations in per cent stocking with time showed trends somewhat differe from those for germination, mortality and numbers of living seedlings. ungraded surfaces, stocking remained relatively high during the period from m June to early September on northeast slopes but dropped off sharply in m August on southwest-facing areas. On graded areas, stocking reached the high values in mid July and early August on both northeast- and southwest-faci slopes and then declined decidedly during the winter months.

On areas having a light herbaceous cover, per cent stocking remained at lo levels throughout the summer and there were never any appreciable differen due to aspect.

Moisture contents of spoil material were generally higher on northe aspects, uncompacted areas and plots having no herbaceous cover (Table Appendix Table 2). Actual differences were not statistically significant at t 2-inch level in the spoil but were significant at the 12-inch level. Similar resu were obtained by Limstrom (1952) in studies of surface-mined areas in Ohio a Kansas. Temperatures measured were significantly higher on southwest- than northeast-facing slopes, a characteristic which also has been noted in studies Bramble (1952), Grandt and Lang (1958) and Schramm (1966). Temperatu also were generally somewhat higher on bare areas than on areas covered wi sparse vegetation, but differences were not statistically significant (Table Appendix Table 2).

TABLE 3. Average moisture and surface temperatures[1] on surface-mined sites broadcast-seeded with black locust in 1958.[2]

Site Condition		Northeast Aspect			Southwest Aspect			Average		
Grading	Herb. Cover	Moisture at: 2"	Moisture at: 12"	Temp.	Moisture at: 2"	Moisture at: 12"	Temp.	Moisture at: 2"	Moisture at: 12"	Temp.
		% by Wt.		°F.	% by Wt.		°F.	% by Wt.		°F
raded	None	19.1	19.4	115.7	18.5	19.0	125.5	18.8	19.2	120.0
raded	Light	19.0	19.1	113.2	18.1	18.7	121.5	18.5	18.9	117.4
ngraded	None	19.4	20.0	112.8	18.7	19.0	123.6	19.0	19.5	118.3
Average		19.2	19.5	113.9	18.4	18.9	123.5	18.8	19.2	118.7

[1]Moisture and temperature readings averaged for the 11 measurement periods during the ımmer of 1958.

[2]See Appendix Table 2 for periodic moisture and temperature readings.

959 AND 1960 SPOT-SEEDING EXPERIMENTS

There were significant differences in results of the 1959 and 1960 ›ot-seeding experiments due to the effects of species, seedbed condition and me. Many of the interactions between these factors were also significant.

Results obtained with the species tested were quite variable. Scarification of lack locust seed was very beneficial, increasing the number of seed which ɜrminated and the maximum number of living seedlings over those obtained ith unscarified seed by approximately 30 per cent in 1959, and by nearly 50 ɜr cent in 1960 (Tables 4 and 5, Figures 2 and 3). The benefits of scarification ıd other seed treatments on germination of black locust also have been noted ı other studies (Chapman, 1936; McKeever, 1937; Meginnis, 1937). Germina-on of both scarified and unscarified black locust began soon after spot-seeding, aching peaks in late May to mid June in both 1959 and 1960. After this, ıortality generally exceeded germination, and numbers of living trees and per ɜnt stocking of spots declined steadily to the end of the growing season ⁼igures 2 and 3, Appendix Tables 3 and 4). Winter mortality of spot-seeded lack locust was high, with per cent stocking of spots being reduced by 30 to 65 ɜr cent during the winter of 1959-1960, and by approximately 30 per cent uring the winter of 1960-1961. Delayed germination of black locust seed was ɜry low.

Results with the pine species were considerably different from those ɔtained with black locust. Total germination and maximum numbers of living ɜedlings of pitch pine were only about 20 per cent as great as that for scarified lack locust in 1959, and about 70 per cent as great in 1960 (Tables 4 and 5, igures 2 and 3). The reason for the better relative performance of pitch pine in 960 as opposed to that in 1959 could not be determined.

TABLE 4. Total germination and mortality of species spot-seeded on surface-mined areas using three methods of seeding in 1959.[1]

Species	Seed Treatment	Method of seeding					
		Surface		Cover with soil		Cover and mul	
		Germ.	Mort.	Germ.	Mort.	Germ.	Mo
		Number of seedlings per 1000 seed spots					
Black locust	Unscarified	100	100	5160	5100	5360	53
Black locust	Scarified	80	80	6820	6740	6960	68
Pitch pine	Unscarified	80	60	1000	460	1100	5
White pine	Unscarified	0	0	260	120	220	2

1See Appendix Table 3 for periodic counts of germination and mortality of seedlings.

TABLE 5. Total germination and mortality of species spot-seeded on surface-mined areas using two methods of seeding in 1960.[1]

Species	Seed Treatment	Method of seeding			
		Surface		Cover with so	
		Germ.	Mort.	Germ.	Mo
		No. seedlings per 1000 seed spots			
Black locust	Unscarified	275	200	1150	23
Black locust	Scarified	650	550	5650	39
Virginia pine	Unscarified	0	0	1750	11
Pitch pine	Unscarified	1100	500	3450	22

1See Appendix Table 4 for periodic counts of germination and mortality of seedlings.

Germination and numbers of living seedlings of white pine spot-seeded 1959 were almost negligible. For Virginia pine spot-seeded in 1960, germinati and living seedlings were considerably lower than for pitch pine spot-seeded the same year. Values were only about 40 per cent as great as those for pit pine and only about 30 per cent as great as those for scarified black locust.

The pattern of variation in germination and survival of the pines was al somewhat different from that shown by black locust. Almost all germination pitch and Virginia pine spot-seeded in 1959 and 1960 occurred soon aft seeding. The maximum number of living seedlings was recorded in early June— approximately the same time as that for black locust (Figures 2 and 3, Append Tables 3 and 4). However, nearly all mortality of pitch and Virginia pi seedlings occurred soon after the peak number was reached. Actual mortality pitch pine in 1959 was very low, while mortality of pitch and Virginia pine

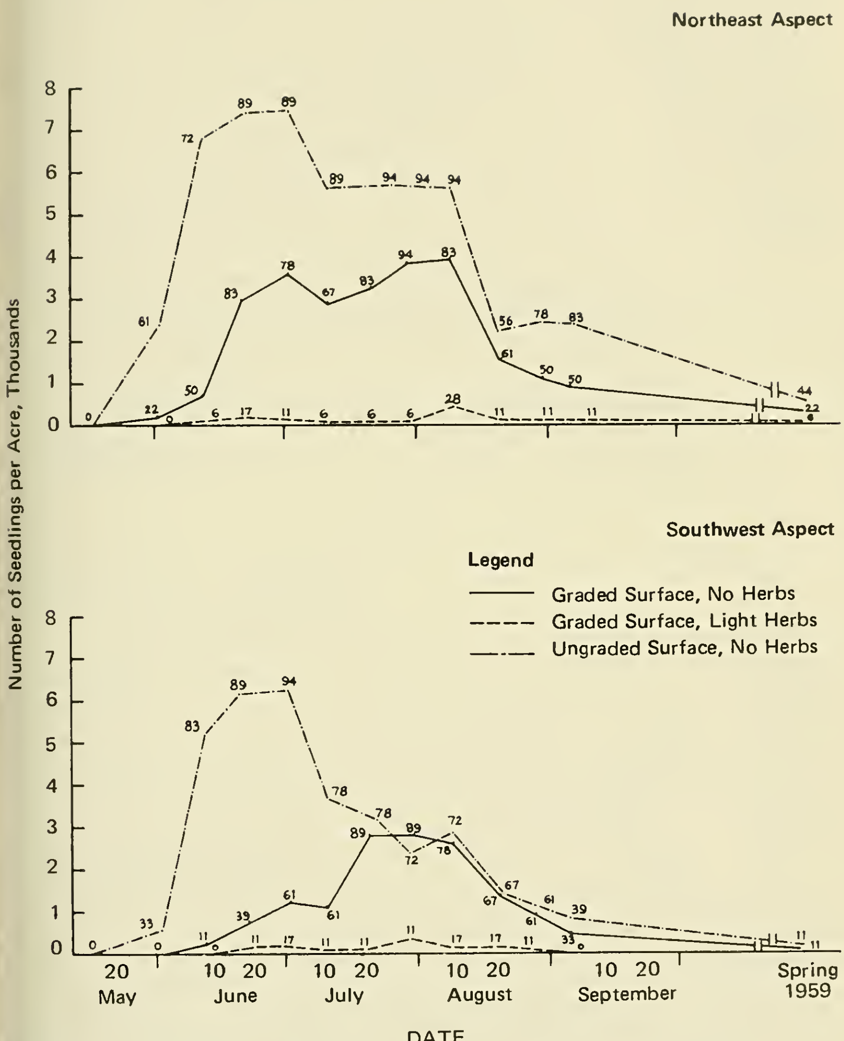


FIGURE 2. Variation in numbers of living seedlings and per cent stocking of plots (numbers over plotted points) for species spot-seeded in 1959 using three methods of seeding on surface-mined areas.

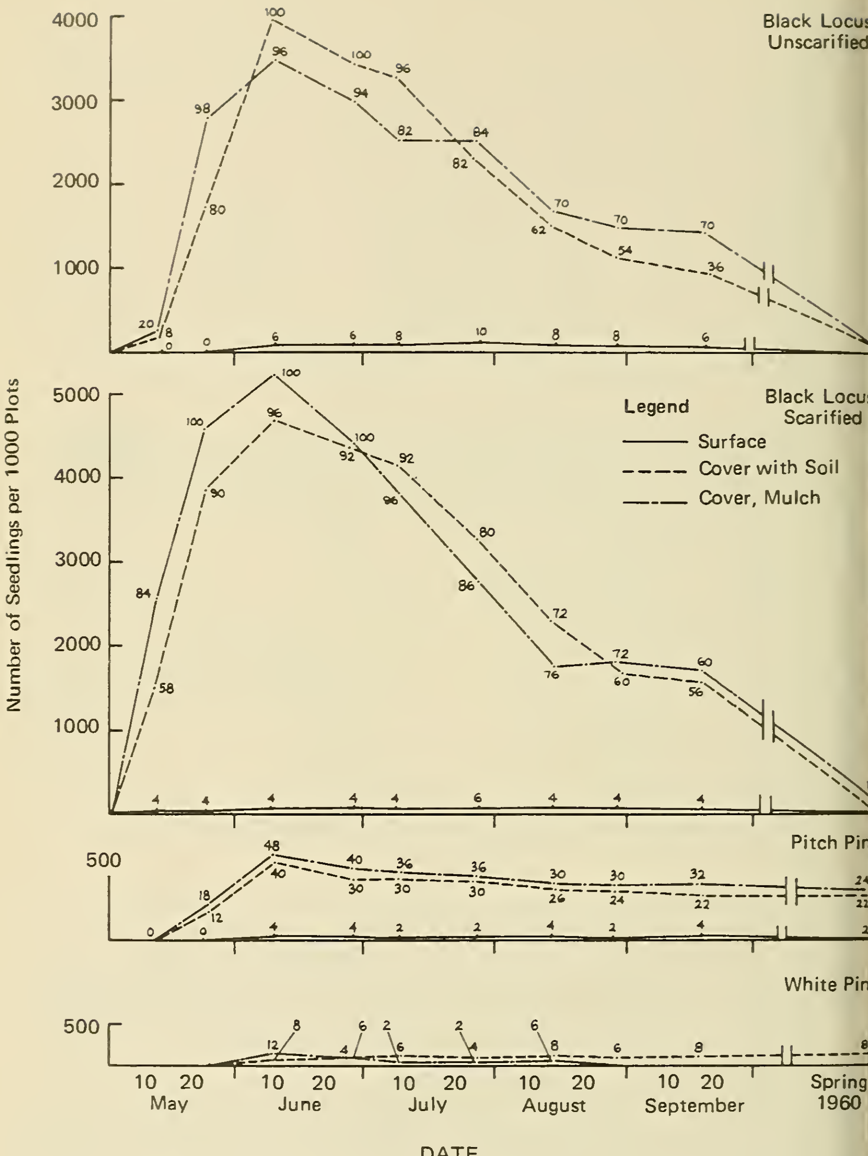


FIGURE 3. Variation in numbers of living seedlings and per cent stocking of plots (number over plotted points) for species spot-seeded in 1960 using two methods of seeding on surface-mined areas.

960 reduced the number of living seedlings to approximately half the peak 'alues recorded in early June.

The effects of seedbed treatment were very pronounced. Covering seed with oil in 1959 and 1960 and covering plus mulching in 1959 proved beneficial to ll species tested. There were no significant differences in 1959 between results ›btained when seed were covered with soil or when seed were covered with soil nd mulched. No germination was recorded for white pine surface-seeded in 959 or for Virginia pine surface-seeded in 1960. In 1959, surface-seeding of carified and unscarified black locust produced only about 1 to 2 per cent as nany seedlings as did covering seed with soil or covering plus mulching (Table ·). In 1960, about 10 per cent as many seedlings resulted from surface-seedings ›f black locust as did seedings in which seed was covered (Table 5).

Best results with a surface-seeded species were shown by pitch pine pot-seeded in 1960. In that year, total germination of surface-seeded pitch pine /as approximately one-third as great as that where spots were covered with soil. .iving seedlings and per cent stocking of plots at the end of the summer were bout one-half that on plots where seed had been covered (Table 5, Figure 3, ıppendix Table 4).

)iscussion and Conclusions

Many of the differences obtained in the three studies can be accounted for ›y variations in soil moisture and temperatures on surface-mined areas. Evidence ›f this is available from the soil moisture and temperature measurements made luring the 1958 broadcast-seeding study. The type and placement of instru-nents used in this study may not have given completely accurate values. Iowever, it was believed that the moisture and temperature readings obtained eflect relative differences in the micro-environments to which germinating seed nd seedlings were exposed.

There were no significant differences in overall moisture content of spoil naterial at the 2-inch layer. However, at times when the spoil material was not t or near field capacity, readings were consistently higher on northeast slopes, ›n uncompacted areas and on areas having no herbaceous cover. These were the ame areas where germination of seed, numbers of seedlings and per cent tocking of plots were most favorable. At the 12-inch layer in the spoil, .ifferences in moisture were significant, again in favor of northeast-facing slopes, ıncompacted areas and sites having no herbaceous cover. Similar differences in noisture at relatively shallow as opposed to deeper layers on spoils having .ifferent site characteristics also were noted in the study by Limstrom (1952).

There are three primary reasons for this. Temperatures are generally lower ›n northeast-facing slopes and evaporation will usually be reduced. Similarly,

moisture loss will be greatest on vegetated areas because of additional loss through transpiration by existing vegetation. On compacted areas, infiltration of rainfall into the spoil is reduced and surface runoff is increased (Limstrom, 1952 and 1960; Merz and Finn, 1951). All of these factors lead to a reduction in available moisture and adversely affect germination of seed and survival of newly germinated seedlings. The absorptive capacity of the newly emerged radicle and the rudimentary root systems of young seedlings is much lower than for older trees (Kramer, 1969). Unless moisture remains relatively high during the critical germination and establishment period, seed will either fail to germinate or many seedlings will die soon after germination.

In addition to indirect effects on evaporation of water, temperature may play a more direct role. Temperatures in excess of 120° F. were common on southwest-facing slopes. General field observations revealed many more instances of "heat girdle" of small seedlings on southwest slopes than on northeast-facing slopes. Such girdles occur near the base of the seedling and are evidence of temperatures which are lethal to the cambial area. Similar evidence of directional orientation of "heat girdle" on seedlings was reported by Schramm (1966).

Compaction also may play another role. Initial root penetration into a compacted surface may be difficult for the newly emerged radicle and unless such entrance is gained quickly, exposure to drying or surface temperatures may result in death before the young tree becomes established. This may, in part, account for the large differences in germination on graded versus ungraded sites. In the studies reported here, a germinated seedling was not counted until the radicle had penetrated the soil and the seedling had attained an upright position.

Variation in the number of living seedlings with time also appeared to follow fluctuations in moisture content and temperatures on spoil areas. On areas where moisture conditions tended to be more favorable (northeast aspects, ungraded areas, and areas with no herbaceous cover), the maximum flush of germination occurred soon after seeding. Where moisture conditions were less favorable, germination was either delayed or spread out later into the summer. Such a delay apparently made seedlings more susceptible to frost heaving and winter kill during the first winter after seeding.

Indirect evidence of the importance of available soil moisture also can be implied from results of the 1959 and 1969 spot-seedings. In both of these studies, seedbed treatments which provided a moist environment for germination (covering seed with soil or covering plus mulching) gave results which were superior to surface seeding. The importance of moisture also can be implied from the data for scarified versus unscarified black locust seed. Scarification allows moisture to penetrate the rather impermeable seed coat of black locust, speeding up to its germination and increasing the establishment of new seedlings.

Differences between species in 1959 and 1960 spot-seedings also have important implications. Some of the variation can be accounted for by seedlot

differences. For example, the germination per cent of black locust was better than that for pitch pine, white pine and Virginia pine. However, these differences were not great enough to account for all the superiority shown by black locust. It would appear that the type and rapidity of germination displayed by black locust is conducive to establishment on surface-mined areas.

The very poor performance of white pine probably can be accounted for by the fact that seed was not scarified. Although total germination in the greenhouse was relatively good, this germination occurred slowly even under the most favorable of moisture conditions. White pine normally displays embryo dormancy and the fluctuating, relatively dry conditions prevailing on the study area would not be favorable for germination.

The poorer performance of Virginia pine when compared with pitch pine probably can be accounted for by seedlot differences. The germination per cent of the Virginia pine seedlot used was considerably lower than that for pitch pine and seeding rate was not adjusted for germination per cent.

In conclusion, it would appear that direct-seeding on surface-mined areas would present a number of uncertainties, even under more favorable conditions. Although seeding rates used in these studies (10 pounds per acre or 10 seed per spot) were higher than those normally employed in direct-seeding operations in the field, numbers of seedlings and/or per cent stocking of plots were still less than might be desirable.

However, steps could be taken which should help to increase the chances of success. When black locust is to be seeded, scarification of seed should be used to hasten germination and early establishment of seedlings. Whenever possible, drier sites—such as southwest-facing slopes—should be avoided.

Site preparation also should be considered. Where direct-seeding is to be used, the amount of regrading might be reduced to allow for better establishment. This does not mean that some regrading should not be done. Other studies (Brown, 1962 and 1973; Brown and Tryon, 1960) in West Virginia have shown that establishment of seed and growth of seedlings is reduced on steeper slopes. Some regrading would help to overcome this problem. A light regrading to provide an uneven, undulating surface probably would be best for establishment of seed. Other site treatments, including disking or covering after seeding (such as hydro-seeding or hydro-mulching), should be beneficial.

In view of results obtained, seeding of tree species on areas having a herbaceous cover should be avoided where possible. The practice of applying tree seed-herb seed mixtures would also be questionable. Herbs often germinate more rapidly, thereby decreasing the germination and establishment of tree seed.

Summary

From 1958 to 1961, studies were conducted to investigate the effects of selected site factors and different seeding methods on the germination and survival of tree species direct-seeded on spoil banks formed by surface mining for coal.

Germination, survival and per cent stocking of plots on spoils broadcast-seeded with unscarified black locust in 1958 were best on northeast-facing slopes, areas which had not been severely compacted by regrading, and on areas having no herbaceous cover. Periodic germination and survival counts indicated that maximum germination, the highest number of living seedlings, and per cent stocking of plots occurred soon after seeding on uncompacted areas and near mid-summer on compacted sites. After maximums were reached, the number of living trees and stocking decreased on all plots until the end of the summer. Winter mortality of seedlings was high on all areas.

Many of the differences noted in the study were found to be related to variations in moisture content and temperatures on study areas. Moisture was highest on those areas where germination, numbers of seedlings, and per cent stocking were best. Temperatures were significantly highest on southwest slopes.

Spot-seedings made in 1959 and 1960 indicated the importance of seed treatment, species and seedbed condition on the success of direct-seeding. Scarification of black locust hastened germination, increased the number of seed which germinated, and increased the number of living seedlings. Results with unscarified white pine seed were very poor. Germination, numbers of living trees and per cent stocking of plots were significantly lower for the pine species (pitch, Virginia and white pines) than for black locust. Almost all germination of pine occurred soon after seeding. This was followed by a sharp reduction in living trees and stocking of plots. Numbers of trees and stocking then remained relatively stable throughout the summer, and winter mortality of pine seedlings was relatively low. Maximum germination and the highest number of living trees for black locust also occurred soon after spot-seeding. However, some germination of black locust took place throughout the summer, and as a result living trees and stocking of plots declined more gradually throughout the summer. Winter mortality of spot-seeded black locust seedlings was high.

The effects of seedbed treatment were very pronounced. On surface-seeded plots, all species showed very low germination, numbers of seedlings, and per cent stocking. Covering of seed with soil or covering plus mulching gave good results, and there were no significant differences in results from the two methods.

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Appendix

APPENDIX TABLE 1. Germination, mortality, living seedlings and per cent stocking[1] for black locust broadcast-seeded on surface-mined areas in 1958.

Date	Northeast aspect Germ.	Mort.	Living	Stock.	Southwest aspect Germ.	Mort.	Living	Stock.
	Number per acre			%	Number per acre			%
GRADED SITES, NO HERBACEOUS COVER								
June 11	232	0	232	22.4	0	0	0	0.0
11	465	0	697	50.0	232	0	232	11.1
20	2381	116	2962	83.3	523	58	697	38.8
July 1	1045	465	3543	77.7	523	0	1220	61.1
10	523	1162	2904	66.7	174	348	1045	61.1
20	929	581	3252	83.2	1975	232	2788	88.8
29	1103	523	3833	94.4	232	232	2788	88.8
Aug. 8	1800	1742	3891	83.3	871	1045	2614	77.7
19	232	2556	1568	61.1	406	1568	1452	66.7
28	116	523	1162	50.0	116	639	929	61.1
Sept. 5	232	465	929	50.0	58	465	523	33.3
Spring, 1959	0	581	348	22.2	0	406	116	11.1
GRADED SITES, LIGHT HERBACEOUS COVER								
June 1	0	0	0	0.0	0	0	0	0.0
11	58	0	58	5.6	0	0	0	0.0
20	116	0	174	16.7	0	0	116	11.1
July 1	58	174	116	11.1	116	58	174	16.7
10	58	116	58	5.6	58	116	116	11.1
20	116	116	58	5.6	116	116	116	11.1
29	58	58	58	5.6	290	58	348	11.1
Aug. 8	406	58	406	27.8	58	232	174	16.7
19	116	406	116	11.1	116	116	174	16.7
28	116	116	116	11.1	58	116	116	11.1
Sept. 5	58	58	116	11.1	116	232	0	0.0
Spring, 1959	0	58	58	5.6	0	0	0	0.0
UNGRADED SITES, NO HERBACEOUS COVER								
June 1	2323	0	2323	61.1	580	0	580	33.3
11	4879	507	6795	72.2	4902	332	5150	83.3
20	3194	2614	7376	88.8	3663	2619	6194	88.8
July 1	3310	3252	7434	88.8	2439	2383	6250	94.4
10	1394	3194	5634	88.8	1122	3615	3717	77.7
20	1626	1568	5692	94.4	680	1145	3252	77.7
29	1278	1278	5692	94.4	430	1301	2381	72.2
Aug. 8	1452	1510	5634	94.4	1160	637	2904	72.2
19	406	3833	2207	55.5	1310	2711	1503	66.7
28	813	581	2439	77.7	353	704	1152	61.1
Sept. 5	639	697	2381	83.3	180	462	870	38.8
Spring, 1959	0	1800	581	44.4	0	695	175	11.1

[1] Per cent stocking based on milacre (1/1000 acre) plots.

APPENDIX TABLE 2. Moisture and temperatures on surface-mined sites broadcast-seeded with black locust in 1958.[1]

	Northeast aspect			Southwest aspect		
	Moisture at:		Temp.	Moisture at:		Temp.
ɪate	2"	12"		2"	12"	
	% by Wt.		°F.	% by Wt.		°F.
ɪRADED SITES, NO HERBACEOUS COVER						
ɪne 1	17.0	17.2	116	16.8	17.0	126
11	16.7	16.5	118	16.5	16.6	127
20	16.6	16.8	115	16.1	16.6	124
ɪly 1	16.8	16.8	120	16.1	16.6	123
10	16.7	16.6	126	16.2	16.3	134
20	28.0	28.0	119	27.0	27.0	122
29	28.0	28.0	116	27.0	28.0	120
.ug. 8	16.8	19.0	118	16.2	17.1	126
19	17.5	17.9	114	17.2	17.7	130
28	18.0	18.1	109	17.4	17.9	126
ept. 5	18.1	18.4	102	16.7	18.0	122
ɪRADED SITES, LIGHT HERBACEOUS COVER						
ɪne 1	17.0	17.0	107	16.6	16.9	114
11	16.7	16.5	106	16.2	16.6	121
20	16.6	16.8	108	16.0	16.1	116
ɪly 1	16.7	16.8	121	15.2	16.1	128
10	16.3	16.5	128	16.2	15.9	129
20	28.0	28.0	120	27.0	28.0	121
29	28.0	28.0	110	27.0	28.0	118
.ug. 8	16.8	16.9	117	15.4	17.1	124
19	17.4	17.7	114	16.3	16.5	127
28	17.9	18.1	107	16.7	17.7	128
ept. 5	17.9	18.1	102	16.7	16.6	110
ɪNGRADED SITES, NO HERBACEOUS COVER						
ɪne 1	17.6	17.0	111	17.0	17.1	115
11	17.3	16.6	113	16.6	16.7	113
20	16.7	18.1	100	16.6	16.7	126
ɪly 1	16.3	16.9	124	16.2	16.6	132
10	16.7	16.7	126	16.2	16.6	131
20	28.0	28.0	114	28.0	27.0	129
29	28.0	28.0	116	28.0	27.0	122
.ug. 8	18.7	22.0	120	16.2	17.1	122
19	17.2	18.0	106	17.2	17.5	124
28	18.1	18.3	106	17.6	18.1	127
ept. 5	18.4	19.9	105	17.2	18.0	119

[1] Field capacity of spoil material was 28 per cent and the wilting point was 13 per cent, a ɪtal of 15 per cent available moisture (by weight).

APPENDIX TABLE 3. Germination, mortality, living seedings and per cent stocking for four species spot-seeded on surface-mined areas using three methods of seeding in 1959.

Date	Surface				Cover with Soil				Cover and Mulch			
	Germ.	Mort.	Living	Stock.	Germ.	Mort.	Living	Stock.	Germ.	Mort.	Living	Stock.
	No./1000 spots			%	No./1000 spots			%	No./1000 spots			%
BLACK LOCUST, UNSCARIFIED SEED												
May 11	0	0	0	0	180	0	180	8	240	0	240	20
23	0	0	0	0	1580	0	1760	80	2560	20	2780	98
June 9	60	0	60	6	2200	0	3960	100	920	220	3480	96
28	0	0	60	6	20	560	3420	100	120	640	2960	94
July 8	20	0	80	8	340	500	3260	96	180	640	2500	82
27	20	0	100	10	200	1220	2240	82	460	440	2520	84
Aug. 15	0	20	80	8	260	1040	1460	62	140	1000	1660	70
28	0	0	80	8	160	520	1100	54	400	600	1460	70
Sept. 19	0	20	60	6	160	320	940	36	320	340	1440	70
Spring, 1960	0	60	0	0	60	940	60	6	20	1400	60	6
BLACK LOCUST, SCARIFIED SEED												
May 11	40	0	40	4	1560	0	1560	58	2560	0	2560	84
23	0	0	40	4	2380	80	3860	90	2000	0	4560	100
June 9	20	0	60	4	1060	260	4660	96	860	220	5200	100
28	0	0	60	4	200	500	4360	92	80	840	4440	100
July 8	0	0	60	4	220	440	4140	92	140	780	3800	96
27	20	0	80	6	500	1360	3280	80	100	1160	2740	86
Aug. 15	0	20	60	4	240	1220	2300	72	360	1340	1760	76
28	0	0	60	4	340	900	1740	60	340	320	1780	72
Sept. 19	0	20	40	4	260	400	1600	56	380	440	1720	60

PITCH PINE												
May 11	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	340	0	340	12	420	0	420	18
June 9	40	0	40	4	580	0	920	40	660	60	1020	48
28	0	0	40	4	0	180	740	30	0	160	860	40
July 8	0	20	20	2	20	20	740	30	0	100	760	36
27	0	0	20	2	20	60	700	30	0	40	720	36
Aug. 15	20	0	40	4	0	80	620	26	0	40	680	30
28	0	20	20	2	0	20	600	24	0	0	680	30
Sept. 19	20	0	40	4	0	60	540	22	20	0	700	32
Spring, 1960	0	20	20	2	40	40	540	22	0	100	600	24
WHITE PINE												
May 11	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
June 9	0	0	0	0	80	0	80	8	140	0	140	12
28	0	0	0	0	80	60	100	4	40	100	80	6
July 8	0	0	0	0	20	0	120	6	0	60	20	2
27	0	0	0	0	0	20	100	4	0	0	20	2
Aug. 15	0	0	0	0	40	0	140	8	40	0	60	6
28	0	0	0	0	0	20	120	6	0	60	0	0
Sept. 19	0	0	0	0	20	0	140	8	0	0	0	0
Spring, 1960	0	0	0	0	20	20	140	8	0	0	0	0

APPENDIX TABLE 4. Germination, mortality, living seedlings and per cent stocking for four species spot-seeded on surface-mined areas using two methods of seeding in 1960.

	Method of Seeding							
	Surface				Cover with Soil			
Date	Germ.	Mort.	Living	Stock.	Germ.	Mort.	Living	Stock.
	No. per 1000 spots			%	No. per 1000 spots			%
BLACK LOCUST, UNSCARIFIED								
May 18	0	0	0	0	0	0	0	0
26	0	0	0	0	2025	0	2025	82.5
June 6	150	0	150	12.5	800	25	2800	90.0
15	25	25	150	12.5	0	200	2600	90.0
27	75	0	225	17.5	25	25	2600	90.0
July 11	0	25	200	15.0	0	225	2375	82.5
27	0	50	150	12.5	25	200	2200	80.0
Aug. 9	0	0	150	12.5	100	75	2225	80.0
29	0	25	125	10.0	100	225	2100	72.5
Sept. 29	25	0	150	10.0	25	825	1300	70.0
Spring, 1961	0	75	75	5.0	50	525	725	40.0
BLACK LOCUST, SCARIFIED								
May 18	0	0	0	0	0	0	0	0
26	75	0	75	7.5	4325	0	4325	85.0
June 6	350	25	400	30.0	775	175	4925	87.5
15	50	200	250	20.0	100	450	4575	82.5
27	75	0	325	25.0	100	275	4400	82.5
July 11	0	50	275	20.0	0	200	4200	80.0
27	0	100	175	17.5	150	400	3950	80.0
Aug. 9	75	75	175	12.5	125	350	3725	80.0
29	0	50	125	7.5	25	475	3275	77.5
Sept. 29	25	0	150	12.5	50	1275	2050	77.5
Spring, 1961	0	50	100	10.0	0	350	1700	60.0

(continued on back cover

APPENDIX TABLE 4. (continued)

Date	Surface Germ.	Surface Mort.	Surface Living	Surface Stock.	Cover with Soil Germ.	Cover with Soil Mort.	Cover with Soil Living	Cover with Soil Stock.
	No. per 1000 spots			%	No. per 1000 spots			%
VIRGINIA PINE								
May 18	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
June 6	0	0	0	0	1700	0	1700	82.5
15	0	0	0	0	25	775	950	52.5
27	0	0	0	0	0	75	875	47.5
July 11	0	0	0	0	0	25	850	45.0
27	0	0	0	0	0	25	825	45.0
Aug. 9	0	0	0	0	0	0	825	45.0
29	0	0	0	0	0	0	825	45.0
Sept. 29	0	0	0	0	25	25	825	45.0
Spring, 1961	0	0	0	0	0	200	625	32.5
PITCH PINE								
May 18	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
June 6	825	0	825	37.5	3250	0	3250	90.0
15	75	175	725	37.5	50	1625	1675	65.0
27	0	25	700	35.0	75	75	1675	60.0
July 11	50	25	725	35.0	0	15	1650	57.5
27	0	25	700	35.0	50	25	1675	60.0
Aug. 9	50	0	750	37.5	0	0	1675	60.0
29	0	25	725	37.5	0	0	1675	60.0
Sept. 29	100	25	800	35.0	25	0	1700	60.0
Spring, 1961	0	200	600	25.0	0	500	1200	45.0